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Flammability, Smoke, and Dry Arc Tracking Tests of Aircraft Electrical Wire Insulations

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July 1989

Final Report

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16. Abstract

Although three different laboratory-scale tests were evaluated in this wire program, only the sixty-degree test is currently required by the Federal Aviation Administration (FAA). All test specimens with the exception of MIL-W-5086/1-PVC nylon passed this test with average burn lengths within the 3-inch maximum and no flame time. The MIL-W-5086/1 samples marginally passed the 30-second flame time, and the average burn length was greater than the 3-inch maximum specified in the FAR.

The smoke test method used in this program called for a straight pilot burner when testing insulated conductor specimens. However, data for a multidirectional pilot burner were also included in this report. Large variations in D_s occurred between the two burners for ETFE constructions at both the 5- and 20-minute test points. The MIL-W-81381/12 aromatic polyimide and the composite construction (Teflon/polyimide/Teflon or TPT) showed no appreciable difference in D_s between the two burner types. Moreover, test duration did not affect smoke generation for these two samples.

A direct correlation can be seen between dry arc tracking tests and wet arc tracking tests (DOT/FAA/CT-88/4). The halogenated polymers formed no conductive chars upon thermal decomposition and, therefore, no dry arc tracking. The MIL-W-81381/12 aromatic polyimide samples formed a conductive char upon thermal degradation, and severe arc tracking occurred. Extensive damage to all wires in the bundle occurred due to arc tracking propagation upon circuit breaker resetting. The TPT composite construction performed well. No dry arc tracking was evident. This construction behaved similarly to a halogenated polymer in this respect.

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EXECUTIVE SUMMARY

New material technology and new Federal Aviation Regulations (FAR) have focused attention on the need to explore additional types of wire insulation testing. This report contains the results of an evaluation of flammability, smoke characteristics, and dry arc tracking of aircraft electrical wire insulations.

The sixty-degree flammability test, as specified in the FAR (appendix A), is the only flammability test required at the present time. All test specimens with the exception of MIL-W-5086/1-PVC nylon passed the sixty-degree test. The average burn length of the PVC nylon specimen was greater than the 3-inch maximum specified in the FAR.

Smoke tests were run in the National Bureau of Standards (NBS) smoke chamber. Flaming combustion was evaluated in this program. Specific optical density (D_s) was evaluated at both the 5- and 20-minute test points. While the smoke test method employed calls for a straight pilot burner when testing insulated conductor specimens, tests were also run with the multidirectional pilot burner. When tested with both burner types at the 20-minute test point, MIL-W-81381/12 aromatic polyimide and the composite construction Teflon™ outer wrap/ polyimide middle wrap/Teflon inner wrap (TPT) had D_s values of under one. Large variations in D_s values between the 5- and 20-minute test points occurred for ethylene-tetrafluoroethylene (ETFE) constructions when testing with both types of burners. Also, D_s values were significantly higher for both modified and unmodified ETFE constructions when tested with the straight versus the multidirectional burner.

Dry arc tracking test results compared well with wet arc tracking test results (DOT/FAA/CT-88/4 "Aircraft Electrical Wet-Wire Arc Tracking"). Severe dry arc tracking occurred for all MIL-W-81381/12 aromatic polyimide samples. Extensive damage to all wires in the bundles was evident. The TPT composite and the halogenated polymer constructions formed no conductive char upon thermal degradation and therefore, no arc tracking occurred.

INTRODUCTION

PURPOSE.

The objective of this project was to evaluate flammability, smoke characteristics, and dry arc tracking resistance of aircraft electrical wire insulations.

BACKGROUND.

At the present time, the only flammability test required for wire insulation is the sixty-degree test in compliance with Part 25.1359(d) in Appendix F of the Federal Aviation Regulations (FAR). With the advent of new material technology and new Federal Aviation Administration (FAA) regulations requiring more stringent flammability and smoke testing of aircraft materials, a need for additional types of wire insulation testing would seem apparent. Two candidates for these additional types of wire insulation testing are a smoke test and a dry arc tracking test.

DISCUSSION

TEST DESCRIPTIONS.

SIXTY-DEGREE TEST. The sixty-degree test evaluates (1) ease of ignition, (2) flame propagation, (3) self-extinguishment time upon flame removal, and (4) flame time of drippings. This test has shown itself to be a quick and effective means for screening flammability characteristics of wire insulations.

SMOKE TEST. In recent years, increased attention has been focused on the effects of smoke emanating from burning aircraft materials. In the confined environment of an aircraft cabin, it is imperative that smoke emission from all sources be minimized as the smoke may cause passenger panic and obscure exits and routes of escape. Transport category aircraft contain miles of wiring, therefore, limiting the smoke produced by wiring insulation in a fire would help to minimize the effects discussed above.

DRY ARC TRACKING TEST. One problem that the United States Navy has encountered is the phenomenon of wet arc tracking (DOT/FAA/CT-88/4 "Aircraft Electrical Wet-Wire Arc Tracking"). While wet arc tracking is not a common occurrence in commercial aircraft, a dry arc tracking test would be beneficial in that a wire insulation's tendency to form a char upon thermal degradation could be characterized. Thermal degradation is primarily initiated by the extremely high temperature of an electrical arc. Upon thermal breakdown, a wire insulation will (1) decompose and give off gaseous byproducts or (2) form a char which may be conductive. If the initial arc were to trip one or more circuit breakers, resetting of the breakers may result in severe damage propagation to the wire bundle if a conductive char is present. This phenomenon is known as arc tracking.

TEST PROCEDURES.

SIXTY-DEGREE TEST. The sixty-degree test was performed in accordance with the procedure specified in Appendix F of Part 25 of the FAR. Refer to appendix A for the test description.

SMOKE TEST. The smoke test was performed in accordance with the procedure specified in the American Society for Testing and Materials (ASTM) Standards F814 titled, "Standard Test Method for Specific Optical Density of Smoke Generated by Solid Materials for Aerospace Applications." Refer to this method for the test description. Only the flaming condition was evaluated in this program. While this procedure calls for a straight pilot burner when testing insulated conductor specimens, data for a multidirectional pilot burner is included in the test results.

DRY ARC TRACKING TEST. This test was performed using a seven-wire bundle cut to a length of 14 inches. Insulation of 3/16 inches was stripped from both ends of each wire. The wires were tied in a six-around-one configuration using an appropriate tying material (waxed linen lacing cord, nylon lacing cord, plastic tie-wraps, etc.) with the tie nearest the end of the bundle, 1/4 inch back on the insulation from the stripped wire ends. A second tie was made around the bundle 2 inches farther back from the first tie. The tie material used was the waxed linen lacing cord.

After the bundle was tied, all the exposed wire ends on one side of the bundle were splayed out such that the strands of each conductor were intermingled with those of adjacent conductors. A small amount of finely powdered conductive graphite was applied to the splayed wire ends to insure that an arc was struck. The bundle was then supported horizontally in a lab stand using two clamps approximately 8 inches apart.

Power was supplied through a 115/220-volt, 400-cycle motor-generator rated at 18.75 kVA. It was located approximately 50 feet from the test stand and was wired to the test bench through a 75- and a 20-ampere circuit breaker inside the generator control box. Individual fuses in a separate fuse box for each phase, a heavy duty manual on-off switch at the test bench, and seven 7-1/2 ampere Klixon™ aircraft circuit breakers in a box on the test bench completed the electrical configuration.

Two breakers were connected to phase "A," two to phase "B," two to phase "C," and one to neutral. All seven test leads had alligator clips on the ends to facilitate connecting to the wires being tested. The test leads were randomly connected to the seven wires in the test bundle. A 3- by 4-foot shield was placed in front of the test setup to protect personnel from the molten metal and burned insulation thrown off when the test arc occurred. Figure 1 is a photograph of the test device.

The test arc was initiated by closing the heavy duty manual switch at the test bench. After the initial arc was struck, only one attempt was made to reset any open circuit breakers. Ten tests were run on each wire sample.

TEST SAMPLES.

Six wire types were evaluated in this test program. Four of these constructions are currently inservice wires:

MIL-W-81381/12 - Kapton™ aromatic polyimide - liquid H-301 topcoat
MIL-W-22759/41 - Extruded radiation cross-linked ETFE
MIL-W-22759/16 - Extruded Tefzel™ (ETFE)
MIL-W-5086/1 - PVC nylon

The fifth wire type evaluated was an experimental composite construction consisting of a Teflon™ outer wrap/polyimide middle wrap/Teflon inner wrap (TPT). The sixth wire type was a proprietary cross-linked irradiated ethylene-tetrafluoroethylene (ETFE). All test specimens were American Wire Gauge (AWG) 20 interconnect wires.

TEST RESULTS.

SIXTY-DEGREE TEST. Table 1 summarizes the results of the sixty-degree test. The average burn length of all samples, with the exception of MIL-W-5086/1 was within the 3-inch maximum specified in the FAR. The average burn length of the MIL-W-5086/1 samples was 5.1 inches, which exceeds the 3-inch maximum.

No flame time after removal of the flame source was recorded for the samples, with the exception of MIL-W-5086/1. The average flame time for MIL-W-5086/1 was 26 seconds. This is within the 30-second time limit defined in the FAR. No drippings from any of the test samples were detected.

SMOKE TEST. Table 2 summarizes the results of the smoke tests performed on the wire test samples. While the ASTM method employed specifies a straight flame burner, some laboratories use the multidirectional burner. Therefore, data for both burners are presented. From table 2, the specific optical density (D_s) for TPT and MIL-W-81381/12 does not significantly vary when comparing 5-minute with 20-minute values for both types of burners. Both TPT and MIL-W-81381/12 produced extremely small amounts of smoke. In both cases, D_s values were under one. When tested with both burner types, MIL-W-5086/1 generated large quantities of dark smoke. Specific optical density values reached the highest number capable of computer generation at the 5-minute test interval (D_s=776.5) therefore, samples were not run for 20 minutes. The MIL-W-22759/16 samples showed a large variation in D_s values between the 5- and 20-minute test intervals for both burners. Moreover, significant differences in D_s values occurred between the two different burners at both the 5- and 20-minute test points with the straight burner producing higher D_s values.

The MIL-W-22759/41 test samples also showed a noticeable difference in D_s values between the 5- and 20-minute test points. This difference occurred with both burner types: again, the straight burner producing higher D_s values than the multidirectional burner. The extruded radiation crosslinked ETFE laboratory samples produced large quantities of smoke. At the 20-minute test point, D_s values for both burners were 775.0. At the 5-minute test point, the D_s was significantly higher with the straight burner (55.5) than the multidirectional burner (7.7).

DRY ARC TRACKING TEST. Tables 3 through 8 summarize the results of the dry arc tracking tests and figures 2 through 7 are photographs of the wire bundles after testing. Table 3 presents the data for the only composite construction among the test specimens. This wire sample incorporated a Teflon outer wrap/polyimide middle wrap/Teflon inner wrap. No dry arc tracking was found. The initial arcs struck were all moderate in severity. Figure 2 shows the TPT wire bundles after testing. Note the appearance of welds and some tube effects (i.e., vaporization of conductor with insulation material remaining). No evidence of carbonization was found on the wire insulation. Data on MIL-W-81381/12 (aromatic polyimide) samples are presented in table 4. All initial arcs were massive in severity and caused multiple circuit breakers to trip. Carbonization of the polyimide due to

the temperature of the initial arc occurred each time. Upon resetting of the circuit breakers, severe re-arcing took place resulting in more insulation degradation. The polyimide samples are shown in figure 3. Tables 5, 6, and 7 summarize arc tracking data on three halogenated polymers. All insulation systems are currently in service. Initial arcs were mild to moderate for all three sets of samples. No dry arc tracking was found for any of the test specimens. Upon resetting of tripped circuit breakers, tables 5, 6, and 7 show that all breakers either stayed in, retripped immediately, or resulted in a small arc restrike followed by a circuit breaker retrip. Figures 4, 5, and 6 show the wire bundles after testing. Note the similar appearance of all three specimens with the welds and tube effects. Minimal insulation damage is seen for all samples. Table 8 presents the data on the laboratory sample of extruded radiation crosslinked ETFE. Five tests were performed due to a shortage of sample wire. Initial arcs were mild to moderate. No dry arc tracking was found. Upon resetting of tripped circuit breakers all breakers retripped immediately or stayed in. The wire bundles are shown in figure 7.

SUMMARY

Although three different laboratory-scale tests were evaluated in this wire program, only the sixty-degree test is currently required by the Federal Aviation Administration (FAA). All test specimens with the exception of MIL-W-5086/1-PVC nylon passed this test with average burn lengths within the 3-inch maximum and no flame time. The MIL-W-5086/1 samples marginally passed the 30-second flame time, and the average burn length was greater than the 3-inch maximum specified in the FAR.

The smoke test method used in this program called for a straight pilot burner when testing insulated conductor specimens. However, data for a multidirectional pilot burner were also included in this report. Large variations in D_s occurred between the two burners for ETFE constructions at both the 5- and 20-minute test points. The MIL-W-81381/12 aromatic polyimide and the composite construction (Teflon/polyimide/Teflon or TPT) showed no appreciable difference in D_s between the two burner types. Moreover, test duration did not affect smoke generation for these two samples.

A direct correlation can be seen between dry arc tracking tests and wet arc tracking tests (DOT/FAA/CT-88/4). The halogenated polymers formed no conductive chars upon thermal decomposition and, therefore, no dry arc tracking. The MIL-W-81381/12 aromatic polyimide samples formed a conductive char upon thermal degradation, and severe arc tracking occurred. Extensive damage to all wires in the bundle occurr due to arc tracking propagation upon circuit breaker resetting. The T composite construction performed well. No dry arc tracking was evident. This construction behaved similarly to a halogenated polymer in this respect.

CONCLUSIONS

1. Specific optical density (D_s) of both modified and unmodified ethylene-tetrafluoroethylene (ETFE) polymers varies significantly when tested with the straight versus the multidirectional pilot burner.

2. No difference in D_s was seen for either Kapton™ aromatic polyimide or the composite construction Teflon™ outer wrap/polyimide middle wrap/Teflon inner wrap (TPT) when tested with both burn holders.

3. No dry arc tracking was seen for any of the specimens tested with the exception of the MIL-W-81381/12 Kapton samples.

4. The Teflon fluoropolymer tapes of the TPT construction prevented dry arc tracking.

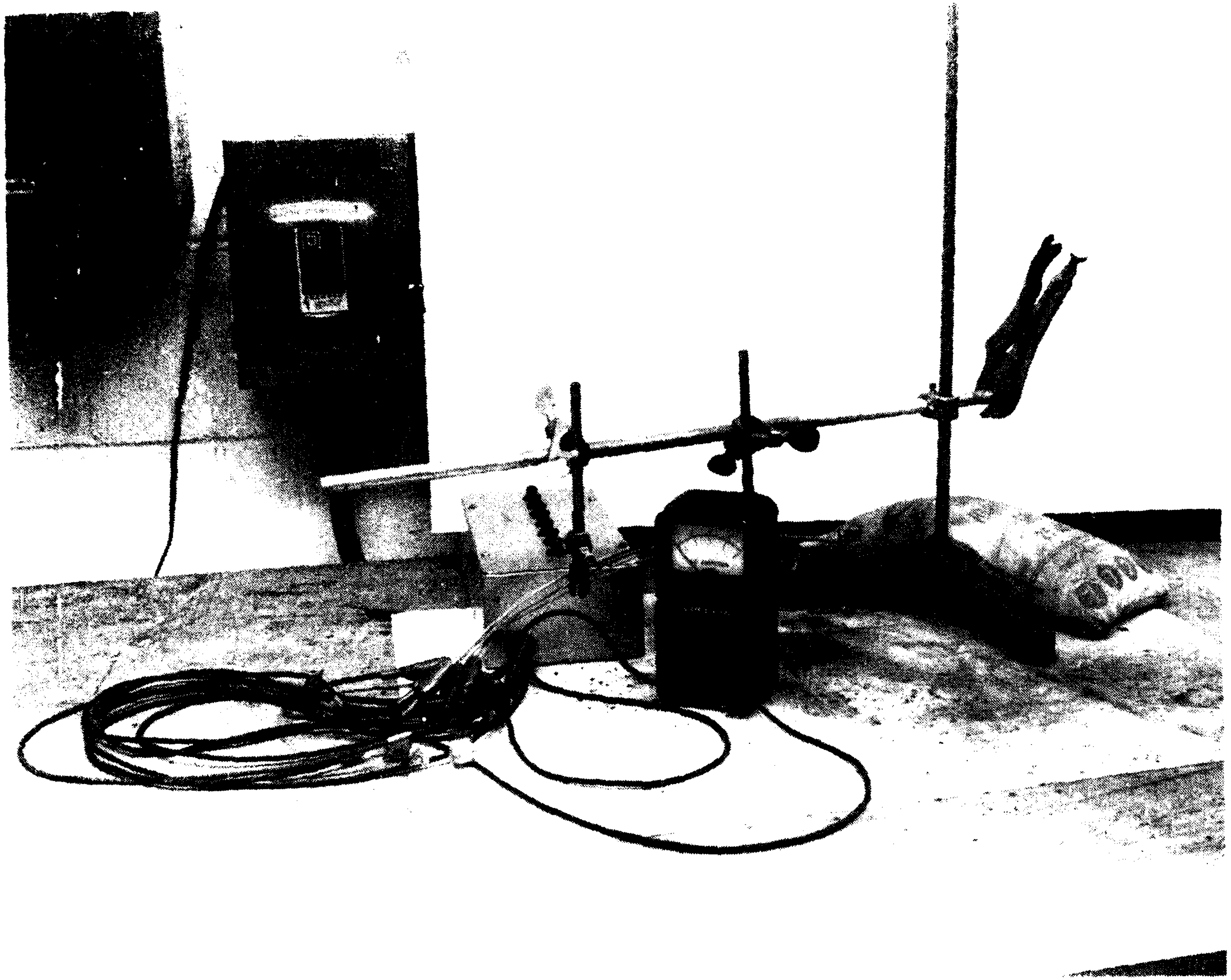

FIGURE 1. TEST DEVICE

TABLE 1. TEST SAMPLE SUMMARY - SIXTY-DEGREE TEST

Material Specification	Burn Length (Average of 3 tests)	Flame Time	Drippings
TPT	1.3 inches	0	0
MIL-W-81381/12	1.4 inches	0	0
MIL-W-22759/16	2.0 inches	0	0
MIL-W-5086/1	5.1 inches	26 seconds	0
MIL-W-22759/41	1.7 inches	0	0
Lab Sample - extruded radiation crosslinked ETFE	1.6 inches	0	0

TABLE 2. TEST SAMPLE SUMMARY - SMOKE TEST

Flaming Combustion Straight Pilot Burner

Material Specification	5-minute D_s (Average of 3 Tests)	20-minute D_s (Average of 3 Tests)
TPT	0.19	0.84
MIL-W-81381/12	0.05	0.36
MIL-W-22759/16	68.60	364.39
MIL-W-5086/1 (PVC) nylon	776.20	not run
MIL-W-22759/41	11.14	182.37
Lab Sample - extruded radiation crosslinked ETFE	55.50	775.00

Multidirectional Pilot Burner

Material Specification	5-minute D_s (Average of 3 Tests)	20-minute D_s (Average of 3 Tests)
TPT	0.013	0.85
MIL-W-81381/12	0.13	0.13
MIL-W-22759/16	18.67	207.12
MIL-W-5086/1	776.52	not run
MIL-W-22759/41	2.86	105.56
Lab Sample - extruded radiation crosslinked ETFE	7.70	775.00

TABLE 3. TEST SAMPLE SUMMARY - DRY ARC TRACKING TEST

Teflon™/Polyimide/Teflon (TPT)

Wire Bundle	Initial Arc	Tripped Circuit Breakers (Upon Initial Arc)	Arc Track	Notes (CB's reset 1 time)
1	moderate	0	no	
2	moderate	0	no	
3	moderate	0	no	
4	moderate	0	no	
5	moderate	0	no	
6	moderate	1	no	CB stayed in
7	moderate	0	no	
8	moderate	2	no	small arc restrike and retrip. CB retripped.
9	moderate	0	no	
10	moderate	0	no	

TABLE 4. TEST SAMPLE SUMMARY - DRY ARC TRACKING TEST

MIL-W-81381/12 - Kapton™ aromatic polyimide

Wire Bundle	Initial Arc	Tripped Circuit Breakers (Upon Initial Arc)	Arc Track	Notes (CB's reset 1 time)
1	massive	4	yes	severe rearcing, all breakers retripped.
2	massive	6	yes	severe rearcing, all breakers retripped.
3	massive	4	yes	severe rearcing, all breakers retripped.
4	massive	6	yes	severe rearcing, all breakers retripped.
5	massive	6	yes	severe rearcing, all breakers retripped.
6	massive	6	yes	severe rearcing, all breakers retripped.
7	massive	6	yes	severe rearcing, all breakers retripped.
8	massive	6	yes	severe rearcing, all breakers retripped.
9	massive	6	yes	severe rearcing, all breakers retripped.
10	massive	6	yes	severe rearcing, all breakers retripped.

TABLE 5. TEST SAMPLE SUMMARY - DRY ARC TRACKING TEST

MIL-W-22759/16 - TEFZEL™ (ETFE)

Wire Bundle	Initial Arc	Tripped Circuit Breakers (Upon Initial Arc)	Arc Track	Notes (CB's reset 1 time)
1	moderate	1	no	CB stayed in.
2	moderate	2	no	Small arc restrike and retrip. CB stayed in.
3	moderate	0	no	
4	moderate	1	no	CB stayed in.
5	moderate	3	no	All CB's stayed in
6	moderate	0	no	
7	moderate	2	no	Small arc restrikes and re-trips for both CBs
8	mild	0	no	
9	moderate	2	no	Both CB's stayed in.
10	moderate	1	no	Immediate retrip.

TABLE 6. TEST SAMPLE SUMMARY - DRY ARC TRACKING TEST

MIL-W-5086/1 - PVC Nylon

Wire Bundle	Initial Arc	Tripped Circuit Breakers (Upon Initial Arc)	Arc Track	Notes (CB's reset 1 time)
1	moderate	0	no	
2	mild	0	no	
3	mild	0	no	
4	moderate	0	no	
5	moderate	1	no	CB stayed in.
6	mild	0	no	
7	mild	1	no	CB stayed in.
8	mild	0	no	
9	mild	0	no	
10	mild	0	no	

TABLE 7. TEST SAMPLE SUMMARY - DRY ARC TRACKING TEST

MIL-W-22759/41 - Extruded radiation crosslinked ETFE

Wire Bundle	Initial Arc	Tripped Circuit Breakers (Upon Initial Arc)	Arc Track	Notes (CB's reset 1 time)
1	mild	0	no	
2	moderate	0	no	
3	moderate	1	no	CB stayed in.
4	mild	2	no	Immediate retrip, CB stayed in.
5	mild	0	no	
6	moderate	0	no	
7	moderate	0	no	
8	moderate	0	no	
9	mild	0	no	
10	moderate	0	no	

TABLE 8. TEST SAMPLE SUMMARY - DRY ARC TRACKING TEST LABORATORY SAMPLE

Extruded radiation crosslinked ETFE

Wire Bundle	Initial Arc	Tripped Circuit Breakers (Upon Initial Arc)	Arc Track	Notes (CB's reset 1 time)
1	moderate	0	no	
2	mild	4	no	All CB's immediately retripped.
3	mild	4	no	All CB's immediately retripped.
4	mild	4	no	CB stayed in. CB retripped. CB stayed in. CB stayed in.
5	mild	1	no	CB stayed in.

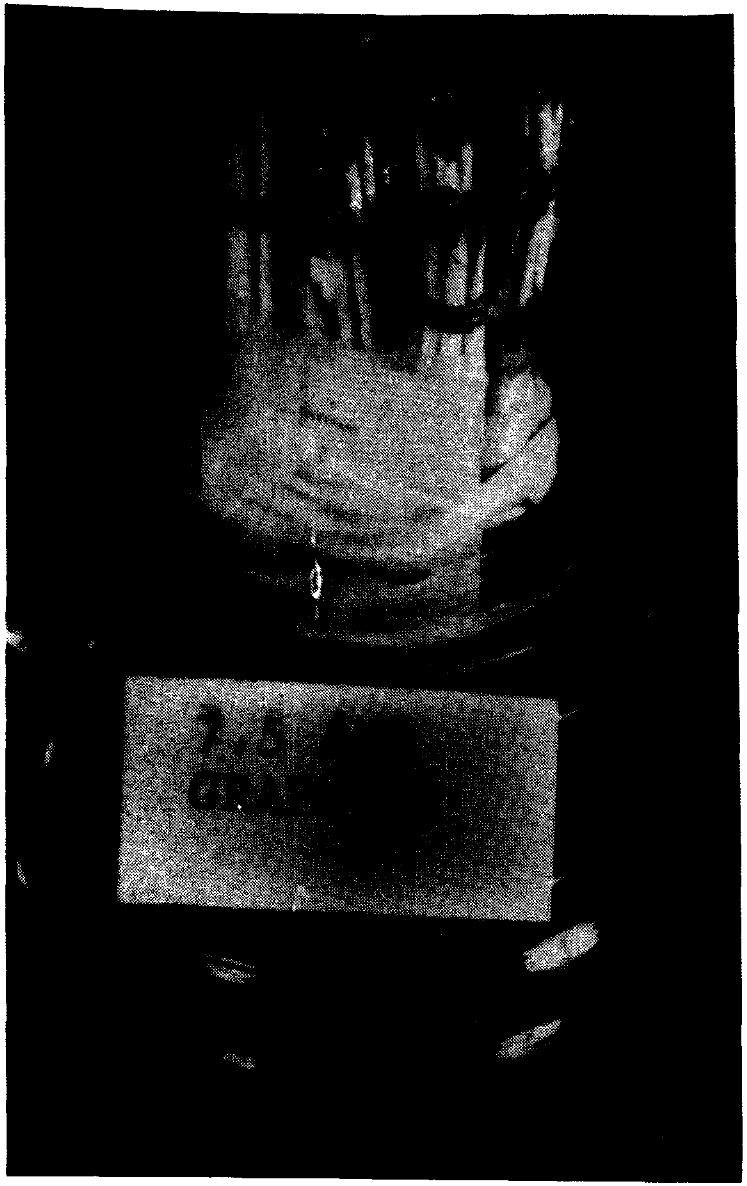

FIGURE 2. TPT PHOTOGRAPH

FIGURE 3. MIL-W-81381/12 PHOTOGRAPH

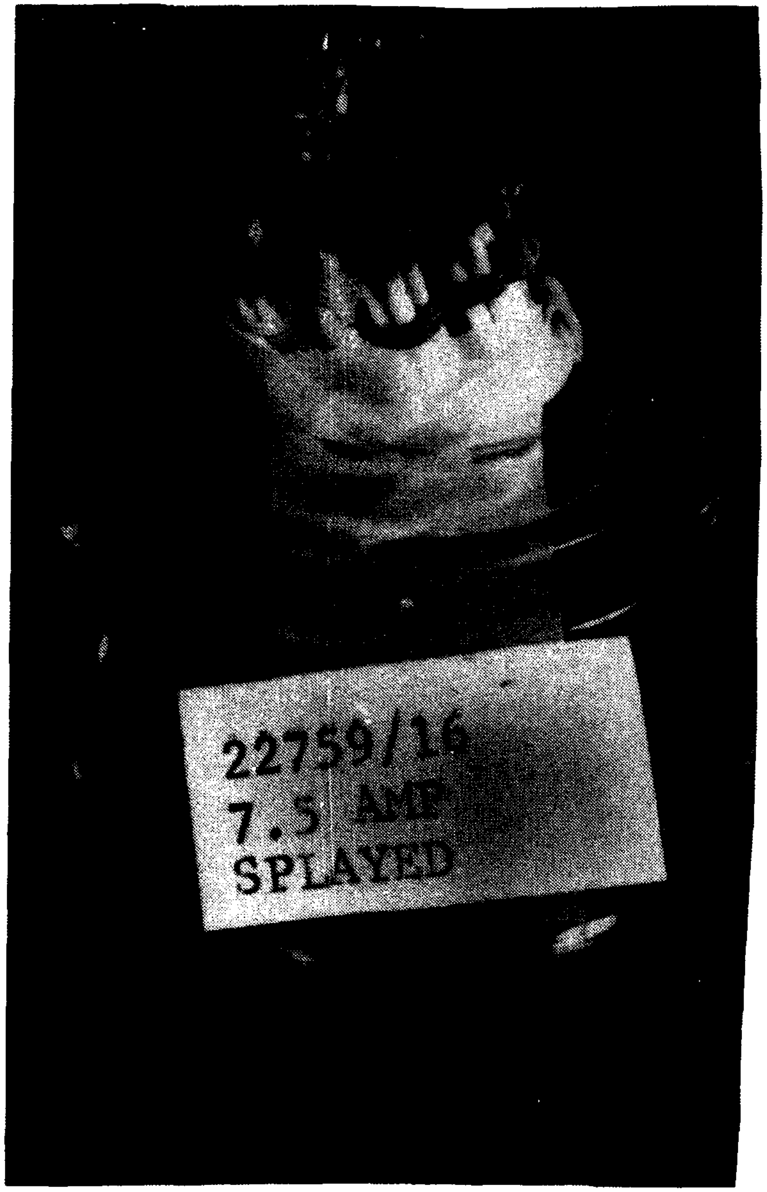

FIGURE 4. MIL-W-22759/16 PHOTOGRAPH

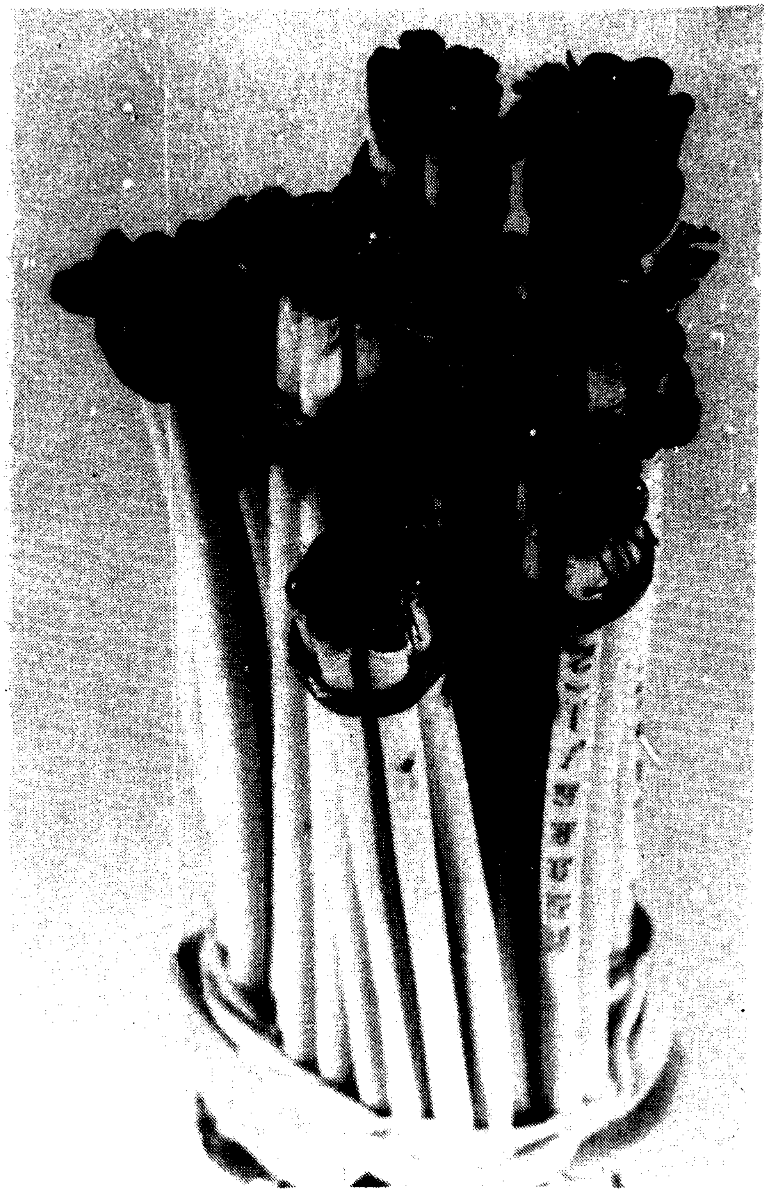

FIGURE 5. MIL-W-5086/1 PHOTOGRAPH

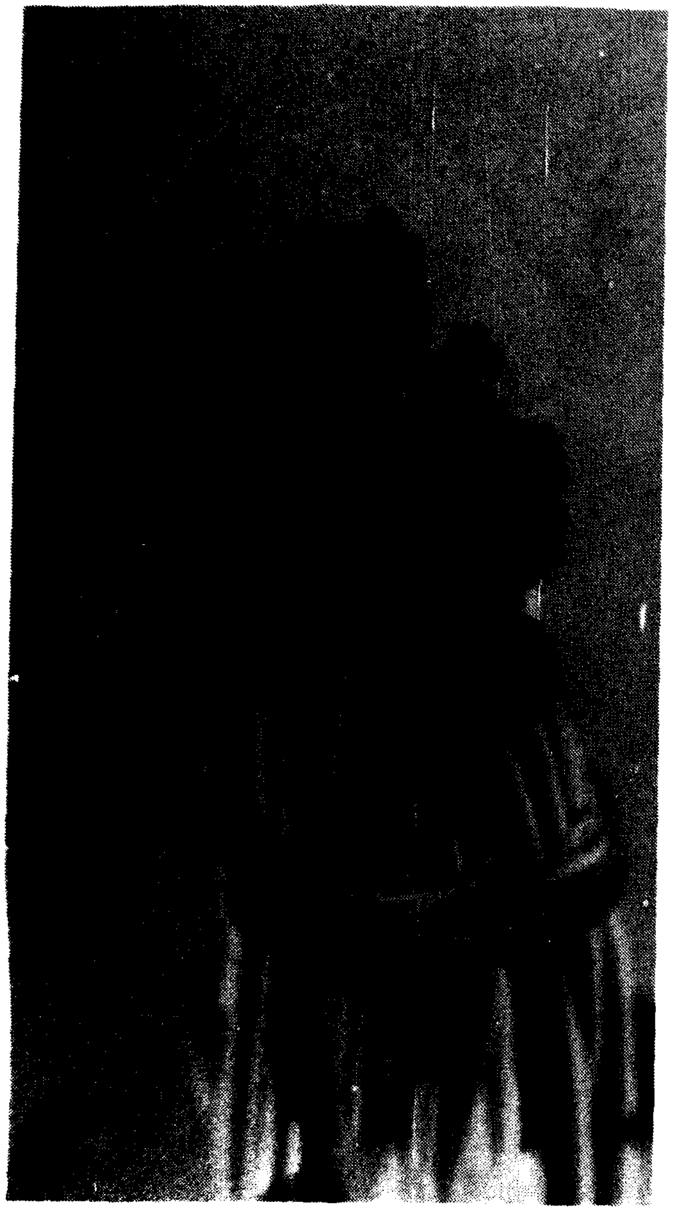

FIGURE 6. MIL-W-22759/41 PHOTOGRAPH

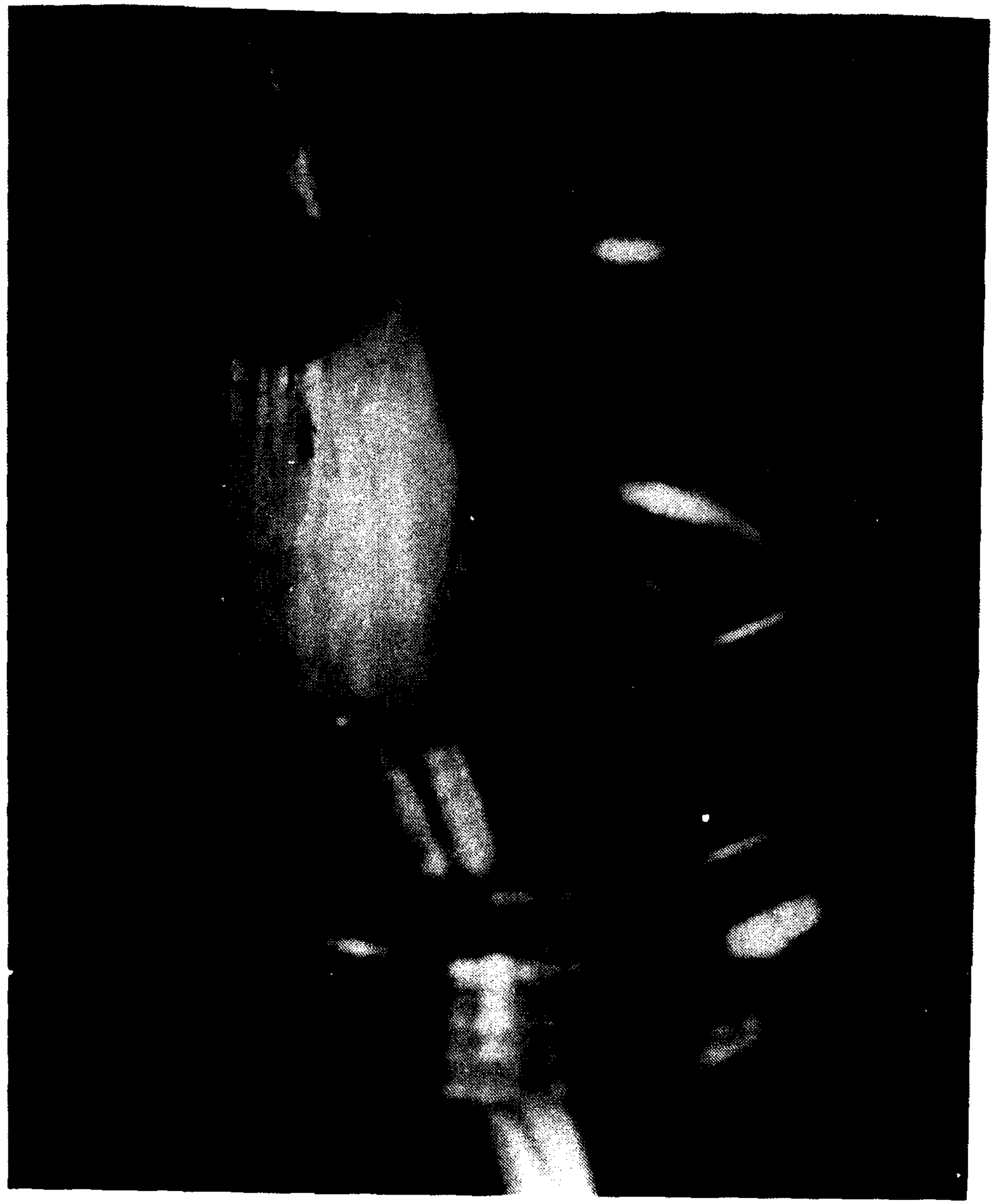

FIGURE 7. LAB SAMPLE PHOTOGRAPH

APPENDIX A - SIXTY-DEGREE TEST

Chapter 1 - Federal Aviation Administration Part 25, App. G

(g) Sixty-degree test in compliance with Part 25.1359(d). A minimum of three specimens of each wire specification (make and size) must be tested. The specimen of wire or cable (including insulation) must be placed at an angle of 60° with the horizontal in the cabinet specified in paragraph (c) of this appendix with the cabinet door open during the test or must be placed within a chamber approximately 2 feet high x 1 foot x 1 foot, open at the top and at one vertical side (front), and which allows sufficient flow of air for complete combustion, but which is free from drafts. The specimen must be parallel to and approximately 6 inches from the front of the chamber. The lower end of the specimen must be held rigidly clamped. The upper end of the specimen must pass over a pulley or rod and must have an appropriate weight attached to it so that the specimen is held tautly throughout the flammability test. The test specimen span between lower clamp and upper pulley or rod must be 24 inches and must be marked 8 inches from the lower end to indicate the central point for flame application. A flame from a Bunsen or Tirrill burner must be applied to 30 seconds at the test mark. The burner must be mounted underneath the test mark on the specimen, perpendicular to the specimen and at an angle of 30° to the vertical plane of the specimen. The burner must have a nominal bore of three-eighths inch and must be adjusted to provide a 3-inch-high flame with an inner cone approximately one-third of the flame height. The minimum temperature of the hottest portion of the flame, as measured with a calibrated thermocouple pyrometer, may not be less than 1,750° F. The burner must be positioned so that the hottest portion of the flame is applied to the test mark on the wire. Flame time, burn length, and flaming time of drippings, if any, must be recorded. The burn length determined in accordance with paragraph (h) of this appendix must be measured to the nearest one-tenth inch. Breaking of the wire specimens is not considered a failure.

(h) Burn length. Burn length is the distance from the original edge to the farthest evidence of damage to the test specimen due to flame impingement, including areas of partial or complete consumption, charring, or embrittlement, but not including areas sooted, stained, warped, or discolored, nor areas where material has shrunk or melted away from the heat source.

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